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Efficacy of Cryosurgery Alone for Refractory Monomorphic Sustained Ventricular Tachycardia Due to Inferior Wall Infarction

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The efficacy of cryosurgery alone was evaluated in 15 patients with refractory monomorphic sustained ventricular tachycardias related to inferior wall infarction. Patients were 64 ± 9 (SD) years old and had a mean left ventricular ejection fraction of 39.2 ± 11.2%. Thirty different tachycardias were mapped with the origin localized to the septum or inferior wall in 20 (67%), near the mitral valve anulus in 6 (20%) and at the base of the posterior papillary muscle in 4 (13%) tachycardias.

Endocardial cryoablation of these sites was performed with 6 to 13 (mean 9.2 ± 1.8) cryolesions per heart. No mitral valve replacement was performed. There was one postoperative death as a result of sepsis. Cryoablation abolished inducible ventricular tachycardia in 11 patients. Of the other three patients, the tachycardia in two was controlled with a single antiarrhythmic agent that had previously failed to suppress inducible ventricular tachycardia. Thus, clinical success was obtained in 13 (93%) of 14 patients. The remaining patient received an automatic implantable cardioverter defibrillator. Ejection fraction remained unchanged or improved after surgery in 14 patients (93%). There have been no late deaths, recurrence of sustained ventricular tachycardia or significant mitral regurgitation during a mean follow-up period of 19 ± 7 months.

These results compare quite favorably with those previously reported for subendocardial resection alone, and indicate that cryosurgery is highly effective, does not result in deterioration of left ventricular function and preserves mitral valve competence when cryoablation of the posterior papillary muscle is necessary.

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The optimal surgical ablative technique in the subset of patients with drug resistant monomorphic sustained ventricular tachycardia related to inferior wall infarction remains uncertain. Localized subendocardial resection in these patients has been associated with a high rate of recurrence of tachycardia when compared with similar surgery performed in patients with anterior myocardial infarction (1,2). Extended endocardial resection together with papillary muscle excision and mitral valve replacement (3,4) has rarely been done because of the high rates of associated mortality and long-term morbidity. Alternative approaches, such as localized or regional subendocardial resection in combination with cryosurgery (5,6), have improved on these surgical results. A preliminary report (7) has suggested comparable success rates with cryoablation alone. However, the efficacy of this procedure as the only ablative technique for patients with inferior wall myocardial infarction remains to be clearly defined. In this report, we examined the efficacy of cryosurgery as the sole procedure for ablation of refractory sustained ventricular tachycardia in such patients.

Study patients. Over a 26 month period, 15 consecutive patients with prior inferior wall myocardial infarction and recurrent monomorphic sustained ventricular tachycardia resistant to multiple antiarrhythmic medications underwent elective cryosurgery.

Patients included in this study satisfied all of the following criteria: 1) spontaneous episodes of ventricular tachycardia manifested as cardiac arrest, syncope or near syncope; 2) inducible sustained ventricular tachycardia while receiving no antiarrhythmic drugs during baseline electrophysiologic study; and 3) failure of several trials of drugs, alone or in combination, to suppress spontaneous or inducible tachycardia.

Preoperative evaluation. Initial electrophysiologic study was performed after discontinuation of all antiarrhythmic agents for at least five half-lives. Induction of ventricular

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tachycardia was done with sequential introduction of single, double and triple extrastimuli at the right ventricular apex or right ventricular outflow tract, or both, after paced rhythms at 600, 400 and 400 to 600 ms (8). Serial electrophysiologic studies were carried out by the same programmed stimulation protocol to test the efficacy of oral antiarrhythmic agents alone or in combination. Surface electrocardiographic (ECG) leads I, II and V_1 were continuously monitored in all studies. Standard 12 lead ECGs of the laboratory-induced ventricular tachycardia were obtained and compared with those available from spontaneously occurring tachycardias. In all such comparisons, one of the induced tachycardias had a configuration and rate similar to those of the patient's clinical tachycardia.

Designation of specific bundle branch block configuration of a tachycardia was based on QRS configuration in lead I or V_1, or both. The QRS complex was labeled as having a left bundle branch block pattern when there was a QS or rS wave in lead V_1 and a right bundle branch block configuration when there was a predominant R wave in lead V_1. In cases where the R and S waves in lead V_1 were of equal magnitude, a predominant R wave in lead I was classified as indication of a left bundle branch block configuration whereas a predominant S wave was labeled as indication of a right bundle branch block configuration. Hemodynamic evaluation was obtained with use of coronary angiography and radionuclide ventriculography at rest.

Intraoperative mapping. After median sternotomy, reference bipolar recording electrodes were placed on the lateral left ventricular wall. Electrodes were also inserted into the right ventricle for bipolar pacing. Epicardial and endocardial mapping of all induced ventricular tachycardias was performed with bipolar roving electrodes located on a fingertip probe or by using a hand-held probe. Mapping was done sequentially around the scar tissues during normothermic cardiopulmonary bypass (9).

Roving and reference electrograms were displayed simultaneously with four surface ECG leads (I, II, V_6R, V_6L) on an Electronics for Medicine VR-16 physiologic recorder and printed at a paper speed of 100 mm/s.

Intraoperatively, a tachycardia was considered to have a left bundle branch block configuration if there was a predominant R wave in lead V_6L or lead I with an S wave in lead V_6R. A right bundle branch block configuration was said to be present if the QRS complex showed an R wave in lead V_6R and S wave in lead V_6L or lead I. If both lead V_6R and V_6L showed R waves or S waves, the QRS complex was described as having a left bundle branch block configuration when both leads manifested R waves and a right bundle branch block configuration when both leads showed S waves.

Electrograms used to determine earliest activation were those that had high amplitude and high frequency components. The time of activation at each mapped site was measured as described by Horowitz et al. (9). An example of intraoperative left ventricular endocardial mapping is shown in Figure 1.

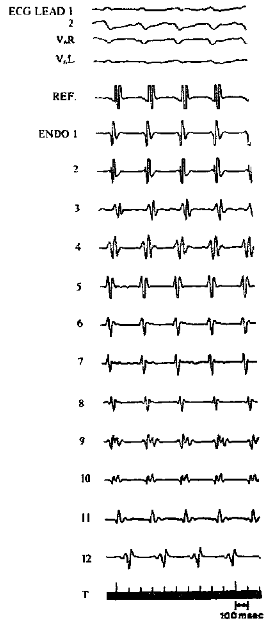

Figure 1. Intraoperative endocardial mapping during ventricular tachycardia. Surface electrocardiograms (ECG LEAD) and reference bipolar electrogram (REF.) are displayed simultaneously with the bipolar electrograms from each site along the endocardial (ENDO) perimeter of the infarcted myocardium. The tachycardia has a left bundle branch block configuration and a cycle length of 285 ms. Site 12 represents the superior margin, site 6 the apical margin and sites 3 and 9 the left lateral and septal margins of the inferior scar, respectively. Earliest activation can be seen at 6 o'clock, which corresponds to the apex, near the lower septum.

Surgical procedures. Endocardial cryoablation was performed at sites of earliest activation: on the border of the scar or aneurysm, at the base of the posterior papillary muscle, at the annular isthmus or at a combination of both. Cryosurgery was done by using a curved probe with a round

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freezing tip of 15 mm diameter (Frigitronics of Connecticut, Inc.) applied to each site for 2 min at −70°C during cold cardioplegic arrest. The number of cryolesions per heart ranged from 6 to 13 (mean 9.2 ± 1.8). No subendocardial resection was performed. Eleven patients underwent coronary bypass surgery and 10 had left ventricular aneurysmectomy. In addition, epicardial patches for the automatic implantable cardioverter defibrillator were placed in seven patients, one of whom had inadequate intraoperative mapping. No valve replacement was performed in any patient. Mean aortic cross-clamp time was 65 ± 20 min (range 31 to 133).

Postoperative electrophysiologic study and follow-up. All operative survivors underwent electrophysiologic testing 10 to 15 days after surgery using the complete stimulation protocol described for preoperative studies. If sustained ventricular tachycardia was still induced, serial drug testing with programmed electrical stimulation was again undertaken. Radionuclide ventriculograms were also obtained 10 to 15 days after surgery to compare left ventricular ejection fraction with that measured before surgery.

After discharge, patients were initially followed up at our arrhythmia clinic and then by their referring physicians. Long-term follow-up data, obtained by telephone interviews, included the following information: recurrence of ventricular tachyarrhythmias, clinical manifestations of heart failure, antiarrhythmic drug therapy, other prescribed medications (including those for heart failure) and degree of physical activity or work.

Definitions. The following definitions were used.

Monomorphic sustained ventricular tachycardia: a ventricular tachycardia with identical beat to beat configuration lasting >30 s, or resulting in loss of consciousness requiring immediate intervention to terminate it.

Site of origin of ventricular tachycardia: the earliest endocardial site of activation during intraoperative mapping identified by the local electrogram in the latter half of diastole. In this study, these were all within a 40 ms period before onset of the surface QRS complex (9).

Surgical success: no postoperative recurrence of sustained ventricular tachycardia (spontaneous or inducible) in a patient without treatment with antiarrhythmic drugs.

Clinical success: surgical success or postoperative spontaneous or inducible (or both) sustained ventricular tachycardia that could no longer be induced after treatment with oral antiarrhythmic agents.

Clinical failure: postoperative recurrence of spontaneous or induced ventricular tachycardia not suppressed by antiarrhythmic drugs.

Statistical analysis. Descriptive variables are reported as mean values ± standard deviations. Statistical analyses were performed by Fisher's exact test and by Student's *t* test. A p value <0.05 was considered to be a statistically significant difference.

Table 1. Clinical Characteristics in 15 Patients

Age (years)	64.2 ± 8.9*
Gender	14 male, 1 female
Time from inferior wall infarction to cryosurgery (months)	103.5 ± 81*
Clinical presentation (n)	
Sudden death syndrome	9 (60%)
Syncope	5 (33%)
Near syncope	1 (7%)
Heart failure (n)	8 (53%)
Coronary arteries with >50% stenosis (no.)	2.2 ± 0.7*
LV aneurysm (no.)	10 (67%)
LV ejection fraction (%)	39.2 ± 11.2*
Drug trials/patient (no.)	4.18 ± 1.16*

*Mean ± SD. LV = left ventricle.

Results

Patient characteristics. Clinical characteristics of the 15 patients are shown in Table 1. There were 14 men and 1 woman; their ages ranged from 45 to 76 years. Inferior myocardial infarction occurred 2 to 276 months (mean 103.5 ± 81) before cryoablation. Ten patients were in New York Heart Association functional class I, and the remaining five in class II.

Preoperative electrophysiologic and intraoperative mapping studies (Table 2). There were 25 morphologically distinct inducible tachycardias during electrophysiologic studies in the 15 patients before surgery. Six patients had a single configuration and nine had two or more configurations of tachycardia. The mean number of tachycardias per patient was 1.7 ± 0.6, and the mean cycle length was 286 ± 65 ms. A right bundle branch block configuration was present in 16 (64%) of the 25 tachycardias. The remaining tachycardias had a left bundle branch block configuration.

Intraoperative endocardial mapping of 30 inducible tachycardias was obtained in 14 patients. Thirteen patients

Table 2. Monomorphic Sustained Ventricular Tachycardia: Electrophysiologic Features in 15 Patients

Preoperative EPS	
No. MSVT/patient	1.7 ± 0.6*
Cycle length (ms)	286 ± 65*
Configuration (n)	25
RBBB	16 (64%)
LBBB	9 (36%)
Intraoperative mapping	
No. MSVT/patient	2.1 ± 0.7*
Cycle length (ms)	276 ± 60*
Configuration (n)	30
RBBB	20 (67%)
LBBB	10 (33%)

*Mean ± SD. EPS = electrophysiologic study; LBBB = left bundle branch block pattern; MSVT = monomorphic sustained venricular tachycardia; RBBB = right bundle branch block pattern.

Table 3. Operative Results and Follow-Up

Operative results	
Postoperative death	1 (7%)
Postoperative EPS	14 (93%)
Inducible VT	2 (14%)
Clinical success	13 (93%)
Clinical failure	1 (7%)
Postoperative LV ejection fraction (%)	41.5 ± 8.6*
Follow-up (19 ± 7* months)	
MSVT recurrence	0
Alive (December 1987)	14 (100%)
NYHA functional class I	10 (71%)
NYHA functional class II	4 (29%)

*Mean ± SD. EPS = electrophysiologic study; LV = left ventricle; MSVT = monomorphic sustained ventricular tachycardia; NYHA = New York Heart Association; VT = ventricular tachycardia.

had multiple tachycardia configurations and one had a single configuration. The mean number of tachycardias per patient was 2.1 ± 0.7 (mean cycle length 276 ± 60 ms). Again, a right bundle block configuration was encountered in a majority by the tachycardias (20 [67%] of 30). In each of these 14 patients, a sustained ventricular tachycardia similar in rate and configuration to the spontaneously occurring or laboratory-initiated tachycardia, or both, was induced in the operating room. However, tachycardias not previously documented were also initiated during intraoperative mapping. The remaining patient with a single clinical ventricular tachycardia initiated during preoperative electrophysiologic study had no inducible tachycardia at surgery. He underwent encircling cryoablation of his inferior scar (10).

Most tachycardias (67%) originated from the septum (12 of 30, 40%) or inferior wall near the apex (8 of 30, 27%). In six tachycardias (20%), the area of earliest activation was between the inferior ventriculotomy and mitral valve anulus (annular isthmus) (5). In four others (13%), the origin was localized to the base of the posterior papillary muscle.

Postoperative results (Table 3). There was no operative death. The only postoperative death occurred 56 days after surgery as a result of sepsis and renal failure, with no recurrence of ventricular tachycardia. Thus, 14 patients (93%) underwent postoperative electrophysiologic testing. No spontaneous or inducible sustained ventricular tachycardia was observed in 11 patients (79%).

Three patients had recurrent ventricular tachycardia. One patient had spontaneous recurrence of ventricular tachycardia on the 5th postoperative day. He had two morphologically distinct tachycardias that were induced before cryoablative surgery. The recurrent tachycardia had the same configuration (right bundle branch block with left axis deviation) as one of two induced at the baseline study. However, the cycle length had slowed to 360 ms from a preoperative value of 240 ms. This patient was treated with oral encainide and follow-up programmed stimulation did not elicit any tachyarrhythmia.

The other two patients had inducible sustained ventricular tachycardia at follow-up electrophysiologic study. In the first patient, the tachycardia had a left bundle branch block configuration with normal axis, which was similar to one of two tachycardia configurations seen during programmed stimulation before cryosurgery. The second patient had two distinct ventricular tachycardia configurations on the baseline study. At the postoperative study, neither of these two configurations was seen, but, a third, previously not seen, ventricular tachycardia (left bundle branch block configuration with left axis deviation) was induced using triple premature stimuli. In the first patient, oral quinidine gluconate successfully suppressed the tachycardia. In the second patient, because induction of tachycardia could not be suppressed with several oral antiarrhythmic regimens, the patient received an implantable automatic cardioverter-defribillator.

As compared with patients who had successful cryosurgery, no significant differences were found in these three patients who had recurrent ventricular tachycardia in regard to clinical presentation, coronary artery disease, left ventricular ejection fraction, ventricular tachycardia characteristics before or during mapping, number of cryolesions or functional class.

Of note, four patients underwent cryoablation at the bases of their posterior papillary muscle. None of them developed postoperative mitral regurgitation. One of them died 56 days after operation as mentioned. In the remaining three, cryosurgery successfully ablated their tachycardias.

Ventricular function. Left ventricular ejection fraction remained unchanged or improved after surgery in 14 (93%) of the 15 patients. In one patient, ejection fraction declined after surgery to 54% from a preoperative measurement of 69%. There was no correlation between the number of cryolesions (6 to 13 per heart) and postoperative changes in ejection fraction. Although the mean ejection fraction improved postoperatively from 39.2 ± 11.2 to 41.5 ± 8.6%, this difference was not statistically significant.

Follow-up (Table 3). The long-term follow-up period ranged from 4 to 28 months (mean 19 ± 7). No spontaneous recurrence of sustained ventricular tachycardia, syncope, defibrillator discharge or late deaths have occurred in these patients. No significant mitral regurgitation has developed in any patient including the three patients who had cryosurgery at the base of the posterior papillary muscle. The two patients who required antiarrhythmic medications to suppress inducible tachycardia postoperatively continued to receive those agents. Ten patients were in functional class I (71%), four of whom were working full time. The remaining four patients were in functional class II (29%).

Discussion

Efficacy of cryosurgery alone. The primary surgical success of subendocardial resection in drug-resistant monomorphic sustained ventricular tachycardia due to inferior wall infarction has been reported to be 50 to 60% (1,5). Our experience has been quite similar and, like others (1,5,6), we have experienced difficulties in ablating ventricular tachycardias in this subset of patients using subendocardial resection alone. However, our results clearly indicate that cryosurgery was highly successful (79%) for ablation of refractory ventricular tachycardia associated with inferior myocardial infarction.

There are several features of inferior wall infarction that may explain the relative lack of success of subendocardial resection: 1) Whereas the papillary muscle is rarely the site of origin of sustained tachycardia in anterior wall infarction, tachycardia frequently originates near or at the base of the posterior papillary muscle (4,6). Resection of this muscle would require artificial valve replacement with its attendant long-term morbidity (3,5,11). On the other hand, if posterior papillary muscle function is preserved by incomplete resection, there is a high probability that recurrence of ventricular tachycardia may follow (4). 2) Inferior wall scars tend to have smaller areas of endocardial fibrosis than do anterior infarcts (1,12). The scars are often patchy in nature with a diffusely mottled appearance and they lack a discrete, well demarcated border, thus making resection difficult. 3) The heavy trabeculation of the endocardium in this region makes it hard to excise a homogeneous layer of tissue (1).

Cryosurgery of posterior papillary muscle. Although the overall frequency with which the posterior papillary muscle is the origin of sustained tachycardias is unknown, the published data (3,4) do suggest that this structure may be the source of recurrent tachycardias and may be incorporated within the inferior wall scar. In addition, mitral regurgitation is a major concern with any surgical procedure involving the papillary muscle. However, in two animal studies (13,14) aggressive cryoablation of the posterior papillary muscle did not result in significant mitral regurgitation. In agreement with those studies, none of the patients in this study who underwent cryoablation at the base of the posterior papillary muscle manifested significant mitral regurgitation during follow-up. Others (6,11) have also reported an uncomplicated clinical course and competent mitral valve after cryosurgery. Thus, the data would indicate that endocardial cryoablation of the posterior papillary muscle is feasible, highly effective and has good long-term results. Cryosurgery appears to preserve mitral valve competence and avoid papillary muscle excision.

Cryosurgery and left ventricular function. In this study, left ventricular ejection fraction remained unchanged after surgery. Others (7) also found no detrimental effects of cryosurgery on ejection fraction. Possible explanations for the preservation of ejection fraction after cryoablation include the following: 1) Cryosurgery does not disrupt the surrounding viable myocardium; it leaves intact the major structural elements while ablating electrically active tissue (15); and 2) the area of damage produced by cryosurgery is small compared with the total left ventricular mass (16). In our patients, there was no correlation between the number of cryolesions per heart (6 to 13) and changes in left ventricular ejection fraction after cryoablation. Thus, the judicious application of cryosurgery to ablate sustained ventricular tachycardia arising from sites of inferior wall infarction does not cause deterioration of ventricular function.

Conclusions. Cryosurgery alone for ablation of drug-resistant monomorphic sustained ventricular tachycardia associated with inferior wall infarction compares quite favorably with subendocardial resection, and seems to offer the following advantages: 1) For tachycardias arising from the papillary muscles, cryoablation preserves mitral valve competence and avoids posterior papillary muscle excision and mitral valve replacement. 2) It is effective in the ablation of ventricular tachycardias originating from poorly demarcated areas of endocardial fibrosis or from apparently "normal" muscle, which are not as amenable to subendocardial resection. 3) It can be safely used in inferior wall scars without resultant impairment of left ventricular performance. 4) Even when cryosurgery was applied to both sides of the septum, no mechanical or functional deterioration was observed (17). Although high septal cryoablation may produce complete heart block (17) (as can any other surgical manipulation in this region), no such complication occurred in our patients.

Our data indicate that cryoablation is highly effective. If future experiences at this and other institutions continue to demonstrate these advantages together with a high degree of success, cryosurgery may become the surgical technique of choice for ablating sustained ventricular tachycardias related to inferior wall infarction.

Addendum

Since submission of this manuscript, three additional patients with medically refractory monomorphic sustained ventricular tachycardia related to inferior myocardial infarction underwent cryosurgery. The procedure was successful in ablating all six mapped distinct tachycardias in these cases as documented at postoperative electrophysiologic testing.

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